

**Basic Research on the Physics of Noise Production
by Centrifugal Pumps**

Principal Investigators: D. K. McLaughlin and D. E. Thompson

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YEARLY SUMMARY OF RESEARCH 1993-94

ONR GRANT NO: N00014-93-1-0374
R&T PROJECT NO: 4322902
Science Officer: Dr. L. P. Purtell

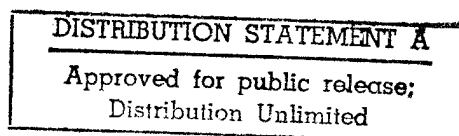


1. Research Goals

The goal of this research is to develop an understanding of the fundamental aspects of the production of noise in centrifugal turbomachinery. Previous investigations at Penn State have revealed two noise production mechanisms. Additional research was initiated to further enhance the understanding of the basic fluid dynamic properties associated with these noise production phenomena. Quantification of noise source types is also desired to determine the kind of interaction present at the impeller trailing edges.

To work toward achieving the goal to develop deeper understanding of the noise production processes, experiments were undertaken in three focus areas.

- 1) Detailed fluid dynamic measurements of the mean and unsteady flowfields were conducted in the impeller channel using rakes of multiple hot-wires (mounted on the impeller).



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- 2) Multi-sensor microphone measurements were performed in the discharge area of the centrifugal impeller.
- 3) The microphone measurements were conditioned using an advanced processing technique to extract the portion of the acoustic signals that is directly attributable to the large-scale instabilities identified and quantified in earlier work.

These measurements provide information on the complicated flow patterns in the impeller and allow us to relate these to the generated noise. The flowfield measurements together with the acoustic measurements provide the information that is needed to develop the understanding of the noise production mechanisms.

2. Accomplishments of Last Year

Hot-Wire Measurements

During the previous year, modifications to the impeller had been made to facilitate positioning of numerous hot-wire sensors in a variety of locations. The modifications entailed extensive design, milling, and refitting the Worthington impeller to accommodate the hot-wire sensors. These modifications were designed to not change the flow characteristics in the impeller passages while still allowing flexibility in probe placement. Also, hot-wire probes of different types have been designed and fabricated at Penn State to efficiently and cost effectively make the flow measurements. Use of preliminary rotating frame data from previous experiments (as an example see the thesis by Jong-Soo Choi (1991)) was utilized to validate the hot-wire designs.

Extensive hot-wire measurements have been performed with multiple sensors, some of which are of the crossed-wire design to facilitate determination of flow direction. Initially these measurements have been used to estimate the character of the secondary flows in the impeller

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channels. This is extremely important since it is the secondary flows that convect the boundary layer turbulence into the middle of the flow channels. The result of such convection is that the flows do not have the character common to non-rotating flow situations in which the turbulence is predominantly confined to the boundary layers. Such phenomena have consequences that are significant in the noise generation process.

Microphone Measurements

As part of our second focus area, extensive multiple-sensor microphone measurements were made in the discharge area of the centrifugal impeller. The practice of component isolation was continued so that the impeller discharged to the open anechoic room (the volute exhaust was removed as in almost all previous measurements). Additionally, the microphones were positioned to the side of the direct flowfield to minimize windage effects. The microphone signals were processed in such a way to attempt to establish the portions of each major type of noise generation method (i.e., monopole, dipole, trailing edge noise, etc.). Initial efforts in this regard involved synchronous averaging with the impeller, using the shaft encoder as the ensemble averaging phase trigger.

Conditioned Microphone Measurements

Further measurements are currently underway using more sophisticated acquisition and processing techniques. Specifically, the acoustic measurements are being ensemble averaged based on a condition of maximum pressure induced by the large scale instability on a pressure transducer mounted on one or two impeller blades. In doing so, a pressure pattern around the periphery of the impeller is established that is synchronized with the instability. Having

established this synchronized pattern, phase relationships between these conditioned components of multiple microphone signals are used to characterize the noise.

3. Future Research

All proof-of-principle hot-wire measurements have been completed demonstrating our capability to make reliable measurements in the rotating frame of mean flow velocities, secondary flows, and turbulence distributions. The turbulence includes the large-scale instabilities, shown to be very important in the noise generation process. The focus of next year's activity in this area will be to conduct detailed measurements at enough probe locations to effectively survey both the mean flow and the unsteady (and turbulence) components. These measurements are performed with a fine enough time resolution to effectively determine all flowfield components of interest in the aerodynamic noise production.

Extensive measurements of the radiated noise field will be made using the conditioned microphone signals. As noted above, the microphone signals are ensemble averaged based on a condition established from the large scale instability measured by a surface mounted pressure transducer. A key ingredient in this investigation will be to modify one impeller blade to produce significantly more noise than the remaining blades. Then, using special logic in the processing code, the noise produced by the one different blade will be isolated from the remaining noise. Establishing the character of such noise (especially its directivity) should provide otherwise unattainable information on the noise generation processes.

OFFICE OF NAVAL RESEARCH
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT
01 October 1993 through 30 September 1994

R & T Number: 4322902

Contract/Grant Title: N00014-93-1-0374

Program Officer: Purtell

Principal Investigators: McLaughlin and Thompson

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|----|--------------------------------------------------------------------------------------------------------------------------------------------------------|----------|
| a. | Number of Papers Submitted to Referred Journal but not yet published: | <u>2</u> |
| b. | Number of Papers Published in Referred Journals (List Attached): | <u>3</u> |
| c. | Number of Books or Chapters Submitted but not yet Published: | <u>0</u> |
| d. | Number of Books or Chapters Published (List Attached): | <u>0</u> |
| e. | Number of Printed Technical Reports & Non-Referred Papers (List Attached): | <u>4</u> |
| f. | Number of Patents Filed: | <u>0</u> |
| g. | Number of Patents Granted (List Attached): | <u>0</u> |
| h. | Number of Invited Presentations at Workshops or Professional Society Meeting
(List Attached): | <u>0</u> |
| i. | Number of Presentations at Workshops or Professional Society Meetings
(List Attached): | <u>4</u> |
| j. | Honors/Awards/Prizes for Contract/Grant Employees:
(List Attached, may include Society Awards/Offices,
Promotions, Faculty Awards/Offices, etc.) | <u>1</u> |

- k. Providing the following information will assist with statistical purposes.

PI/CO-PI:	TOTAL	<u>2</u>	Grad Students:	TOTAL	<u>2</u>
	Female	<u>0</u>		Female	0
	Minority	<u>0</u>		Minority	0
			Post Doc:	TOTAL	<u>0</u>
				Female	<u>0</u>
				Minority	<u>0</u>

TECHNOLOGY TRANSFER

The method of separating a source signal from a signal which contains both the source signal and transmission effects has been used in several Navy research programs at ARL Penn State. The particular application adapts the method developed by Mongeau ("Method for Characterizing Aerodynamic Sound Sources in Turbomachines") to a propeller shaft upon which the propeller unsteady forces are being measured. These unsteady force measurements are contaminated by shaft vibration. The method removes the vibration effects and produces the desired unsteady forces. This method has been used for both model and full-scale measurements.

Additionally the method described above has also been adopted by the following organizations: 1) United Technologies Research Center (R.H. Schlinker), 2) AT&T Bell Labs, computer cooling fan quieting, (P.H. Bent), and 3) Purdue University Herrick Laboratories (L. Mongeau), 4) Ingersoll-Rand, pump quieting work, 5) Allison Engine Company, turbine engine quieting (P. Tramm), 6) CDNSWC - ANN, pump quieting.

LIST OF PUBLICATIONS/REPORTS/PATENTS/GRADUATES

1. Papers Published in Referred Journals:

Mongeau, L., D. E. Thompson, and D. K. McLaughlin, **"Sound Generation By Rotating Stall in Centrifugal Turbomachines,"** *Journal of Sound and Vibration*, Vol. 163, No. 1, 1993, pp. 1-30.

Mongeau, L., D. E. Thompson, and D. K. McLaughlin, **"Method For Characterizing Aerodynamic Sound Sources in Turbomachines,"** Accepted for publication in *Journal of Sound and Vibration*, March 1993.

Dorney, D. J., Davis, R. L. and McLaughlin, D. K., **"Numerical Simulations of Flows in Centrifugal Turbomachinery."** Accepted for publication in the *AIAA Journal*, October 1994.

Choi, J. S., D. K. McLaughlin, and D. E. Thompson, **"Measurements of Large Scale Instability Noise Generators in a Centrifugal Turbomachine."** To be submitted for publication to *American Society of Mechanical Engineers, Journal of Turbomachinery*, November 1994.

Bent, P.H. and D.K. McLaughlin, **"Enhancements to Noise Source Measurement Techniques for Turbomachinery,"** to be submitted to the *Noise Control Engineering Journal*, November 1994.

2. Books (and sections thereof) Published:

None

3. Technical Report, Non-Refereed Papers:

Bent, P.H., McLaughlin, D.K., and Thompson, D.E., **"Influence of Flow Rate on Aerodynamic Noise Generation in Centrifugal Turbomachinery,"** Proceedings of the National Conference of Noise Control Engineering, Williamsburg, VA, May 2-5, 1993.

Dorney, D.J., Davis, R.L., and McLaughlin, D.K., **"Numerical Simulations of Flows in Centrifugal Turbomachinery,"** AIAA Paper No. 93-2578, AIAA/SAE/ASME/ASEE 29th Joint Propulsion Conference and Exhibit, Monterey, CA, June 28-30, 1993.

Tetu, L.G., D.E. Thompson, and D.K. McLaughlin, **"Aeroacoustic Similarity of Centrifugal Turbomachinery of Different Geometries,"** AIAA Paper No. 93-4371, 15th AIAA Aeroacoustics Conference, Long Beach, CA, October 25-27, 1993.

3. Technical Report, Non-Refereed Papers: (Cont'd)

Bent, P.H., and D.K. McLaughlin, **"Enhancements to Noise Source Measurement Techniques for Turbomachinery,"** AIAA Paper No. 93-4373, 15th AIAA Aeroacoustics Conference, Long Beach, CA, October 25-27, 1993.

4. Presentations:

Bent, P.H., McLaughlin, D.K., and D.E. Thompson, **"Influence of Flow Rate on Aerodynamic Noise Generation in Centrifugal Turbomachinery,"** Presented at the National Conference of Noise Control Engineering, Williamsburg, VA, May 2-5, 1993.

Dorney, D.J., Davis, R.L., and McLaughlin, D.K., **"Numerical Simulations of Flows in Centrifugal Turbomachinery,"** Presented at the AIAA/SAE/ASME/ASEE 29th Joint Propulsion Conference and Exhibit, AIAA Paper No. 93-2578, Monterey, CA, June 28-30, 1993.

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5. Patents Granted:

None

6. Degrees Granted (name, date, degree):

Paul H. Bent	PhD Received:	Dec. 1992
Lee G. Tetu	MS Received:	Aug. 1993, PhD Candidate
Matt Hettenhouse	MEng Received:	Aug. 1994

LIST OF AWARDS/HONORS/PRIZES

Name of Person(s) Receiving Award

Daniel J. Dorney
Roger L. Davis
Dennis K. McLaughlin

Recipients' Institution

Dorney -United Technologies Research Center and Penn State University
Davis - United Technologies Research Center
McLaughlin - Penn State University

Name of Award

AIAA Air Breathing Propulsion Technical Committee Best Paper for 1993 for, "Numerical Simulations of Flows in Centrifugal Turbomachinery."

Sponsor of Award

American Institute of Aeronautics and Astronautics

OTHER SPONSORED RESEARCH

(Include title, sponsors's name, dollar amount and start and end dates for the award)

"Computation of Random Unsteady Flow Field and Resulting Broadband Noise in Marine Propulsors, Cooling Centrifugal Pumps, and Ventilating Fans," B. Lakshminarayana and D. E. Thompson, ONR Code 1215, FY 90 - \$96.5K, FY 91 - \$105K, FY 92 - \$113K, FY 93 - \$115K.

"Stage Flow High Reynolds Number Flow Database," D. E. Thompson, ARPA, FY 93 - \$250K.

"Rotor/Casing Interaction," D. E. Thompson, ONR, FY 92 - \$90K, FY 93 - \$250K., FY 94 - \$80K.

"Rotor Unsteady Response," D. E. Thompson, ONR, FY 93 - \$315K, FY 95 - \$250K.

"The Aeroacoustics of Supersonic Jets," D. K. McLaughlin and P. J. Morris, NASA Langley, \$186,505, April 1, 1992 - March 31, 1995.

"Mixing Enhancement in Supersonic Shear Layers," D. K. McLaughlin, L. N. Long and P. J. Morris, NASA Lewis Research Center, \$99,992, April 28, 1993 - October 31, 1994.

"Experiments on the Dominant Noise Sources in Centrifugal Turbomachinery Operating On and Off-Design," D. K. McLaughlin and D. E. Thompson, Office of Naval Research, \$56,485, November 1, 1992 - April 30, 1994.

FUNDING BALANCE

Approximately \$35,000 as of September 30, 1994.